

NOTE

SELECTIVE DEFICIT IN PROCESSING DOUBLE LETTERS

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ABSTRACT

This paper reports a patient with a selective difficulty in spelling words and pseudowords with geminate (double) consonants. In all writing tasks, deletions of a geminate consonant occurred ten times more often than deletions of a consonant in a non-geminate cluster. In addition, the probability of substituting *both* geminate consonants was indistinguishable from the probability of substituting *one* consonant in a non-geminate cluster; and, the probability of substituting only one geminate consonant was close to zero, and significantly lower than the probability of substituting one consonant in a non-geminate cluster. This pattern of performance is consistent with the hypothesis that grapheme quantity and identity are separately represented in orthographic representations. The fact that these errors occurred in the absence of a significant number of geminate transpositions is interpreted as support for the hypothesis that letter gemination is specified by a "doubling feature."

INTRODUCTION

Brain damage sometimes produces highly selective cognitive, perceptual or motor deficits. Analyses of these deficits have been used to inform theories of normal cognitive, perceptual and motor processing (see., e.g., Shallice, 1988, for review). A particularly productive area of inquiry has been the domain of lexical processing. The investigation of disorders of aural and visual comprehension and of oral and written production of words has served as the basis for fairly detailed claims about the structure of lexical processes. These claims have concerned not only the overall organization of the major components of the lexical processing system but increasingly also the internal organization of specific components of the system. Thus, for example, the analysis of the performance of patients with selective deficits in processing different categories of words (e.g., animate vs. inanimate: Warrington and Shallice, 1984; proper vs. common nouns: Semenza and Zettin, 1988; Lucchelli and De Renzi, 1992; nouns vs. verbs: Caramazza and Hillis, 1991; Zingeser and Berndt, 1988) has provoked considerable speculation about the type and organization of the information that is stored in the semantic, phonological and orthographic components of the lexical system (e.g., Caramazza, Hillis, Leek et al., 1994; Garrett, 1992). Similarly, the analysis of different types of spelling errors in dysgraphic patients has led to the formulation of specific hypotheses about the structure of graphemic representations in spelling (Caramazza and Miceli, 1989, 1990). In this paper we report the performance of an Italian dysgraphic patient (SFI) whose selective deficit in spelling words with geminate (double) consonants (e.g., *matton*, brick) further constrains claims about the structure of graphemic representations, specifically with regard to the manner in which double letter information is represented.

Correct spelling requires access to knowledge of the graphemes that jointly constitute the spelling of a word. For example, spellers of English know that the anatomical part of the body /fit/ is spelled *feet* and not *feat*, *feett*, *phheet*, *phfeat*, etc., although any of these forms would have done as well. Similarly, spellers of Italian know that /a:kua/ is spelled *acqua* and not *accua*, or *aqqua*. What does this knowledge consist of and how is it

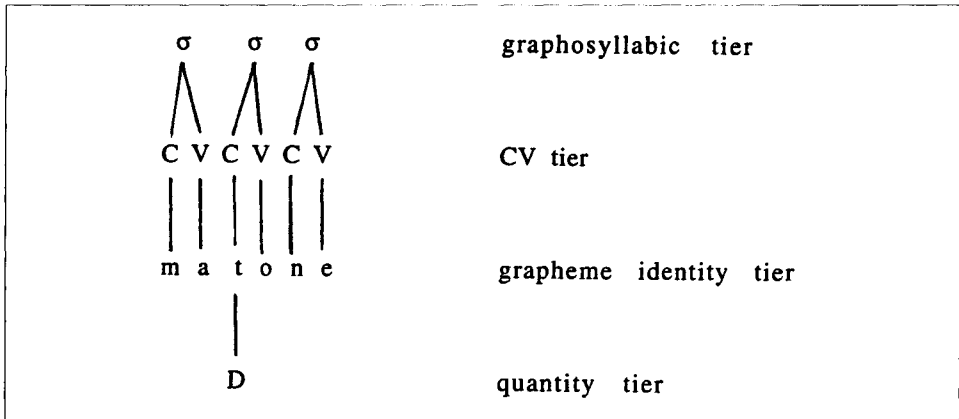


Fig. 1 – The orthographic representation of the word *mattonne*, brick, according to Caramazza and Miceli (1990).

represented? Caramazza and Miceli (1989, 1990) have proposed that graphemic representations are complex multidimensional objects in which different dimensions specify different types of information about graphemic structure. Specifically, these authors have proposed that in addition to information about the identity and order of graphemes, graphemic representations also specify (1) the consonant/vowel status of each grapheme, (2) whether a grapheme is a singleton or a geminate, and (3) the graphosyllabic structure of the graphemic string. In this framework, the graphemic representation of the Italian word *mattonne* would be as shown in Figure 1. The empirical evidence that has been adduced in support of these claims has come mostly from the analysis of the spelling errors of dysgraphic patients, and has principally concerned the CV and the quantity levels (tiers) of representation (Caramazza and Miceli, 1989, 1990; Cubelli, 1991; McCloskey, Badecker, Aliminosa et al., 1994; Tainturier and Caramazza, 1995; but see Jonsdottir, Shallice and Wise, 1994, for an alternative view).

One type of evidence in support of the proposed multidimensional structure of graphemic representations concerns the distribution of substitution and transposition errors produced by dysgraphic patients as a function of the orthographic structure of the target response. Thus, for example, the substitution and transposition errors produced by LB (Caramazza and Miceli, 1990) virtually always involved the substitution and transposition of one consonant for another (e.g., *sapore* → *sarore*; *nipote* → *pinote*) or one vowel for another (e.g., *calice* → *celice*; *figure* → *fugire*). The fact that substitution and transposition errors respected these highly restrictive conditions was interpreted as implying that the consonant/vowel status of graphemes is represented independently of their identity. Similarly, the fact that LB's transposition errors with geminate clusters, unlike other consonant clusters, always involved both letters in the cluster (e.g., *tropo* → *protto*, but not *protpo* or *propto*) was interpreted as indicating that double letters are represented by a single grapheme type with a marker that specifies that two tokens of the grapheme should be produced (see also Rumelhart and Norman, 1982; but see McCloskey et al., 1995, for an alternative representational format).

The proposed structure for graphemic representations substantially restricts the types of possible forms of selective deficits that may be observed in spelling performance. For example, the hypothesis that the consonant/vowel status of graphemes forms part of the graphemic representations computed for output allows the prediction that it ought to be possible to selectively damage consonants or vowels. In accord with these expectations, Cubelli (1991) has reported the performance of two dysgraphic patients who were selectively impaired in producing vowels. Similarly, the proposal that information about quantity (letter doubling) is specified independently of information about the identity of graphemes allows the prediction that the two types of information may be selectively affected by brain damage. Thus, it ought to be possible to find dysgraphic patients who are selectively impaired in producing double letters. Here we report just such a case.

CASE HISTORY

SFI is a 41 year-old, right-handed man with an 8th grade education. He did not report having reading or writing problems prior to his stroke. SFI worked as a laboratory technician when he suffered from a deep left-hemisphere hemorrhage. An MRI performed 1 year post-onset showed a putaminal lesion, extending to the frontal and parietal white matter, with consensual enlargement of the parietal portion of the left lateral ventricle, and diffuse frontal and parietal leucoencephalopathy. Representative cuts of the MRI are shown in Figure 2.

The patient was seen for the first time approximately six months post onset, and was tested at the IRCCS S. Lucia for approximately six months (July, 1992 through January, 1993). His spelling deficit remained stable throughout this period of time. He presented with right hemiplegia and hypoesthesia. Visual fields and auditory perception were within normal limits on confrontation tests, including double simultaneous stimulation in the visual and in the auditory modality, respectively.

Neuropsychological Testing

Testing revealed a mild but clear loss of verbal memory. Recognition memory, assessed by probe tasks, was normal for words and only mildly impaired for pseudowords. Reproduction memory was mildly impaired for words, more clearly defective for pseudowords. SFI produced correct responses to 10/10, 9/10, 2/5 and 0/5 series of 2, 3, 4 and 6 words respectively, and to 7/10 series and 0/10 series of 2 and 3 pseudowords, respectively. Digit span was reduced (4 digits forward, 3 digits backward). Scores on clinical tests of buccofacial praxis were within normal limits, but verbal and non-verbal agility were mildly (and comparably) reduced.

SFI achieved normal scores on Raven's Colored Progressive Matrices. Visual memory, visual-spatial abilities, limb praxis and constructional praxis were well within normal limits.

Language Testing

SFI was submitted to a screening battery for aphasia (Miceli, Laudanna and Burani, 1991). He showed a very mild aphasic deficit.

SFI normally processed auditory input in tasks that required auditory discrimination and auditory-visual matching of minimal pairs of phonemes embedded in CV syllables. He also performed flawlessly in a same-different judgment task (100 same and 100 different pairs), in which he was asked to discriminate between two words (*cane*, dog - *canne*, straws), two pseudowords (*mudo* - *muddo*), or a word and a pseudoword (*passo*, step - *passo*, pseudoword), presented auditorially, which could differ only for the presence/absence of geminate consonants. These consonant contrasts are phonologically distinctive in Italian. He also performed at a normal level in auditory and visual tasks that required lexical decision, grammaticality judgment, word-to-picture matching and sentence-to-picture matching.

SFI repeated and copied (in delayed copy) both words and pseudowords flawlessly. He repeated correctly 12/13 sentences (92.3%), for a total of 85/86 words (98.8%). In reading aloud, he produced the correct response to 35/45 pseudowords (77.8%), to 90/92 (98.8%) words and to 6/6 sentences (for a total of 37 words). All incorrect reading responses were near misses, resulting in substitutions, insertions, deletions, and shifts/transpositions of letters/phonemes (e.g., in pseudoword reading, *erda* → *erna*; *stighe* → *stinghe*; *nobbia* → *no_bia*; *qualerco* → *quarleco*).

In writing-to-dictation tasks, SFI produced correct responses to 8/10 polysyllabic pseudowords (80%), and to 37/46 words (80.4%). Errors consisted of letter substitutions (*giace* → *giage*), insertions (*spaventa* → *spaventta*) and deletions (*orgoglio* → *orgo_lio*; *bloccare* → *blo_care*). Four errors in writing involved geminate consonants (3 consonant deletions, and 1 insertion of a geminate cluster in a word that did not have a geminate cluster).

SFI performed flawlessly in oral naming of objects to description (20/20). His performance in oral naming of pictures was much better preserved than written naming: he responded correctly to 54/58 pictures (92.3%) in oral naming, and to 32/44 pictures (72.7%) in written

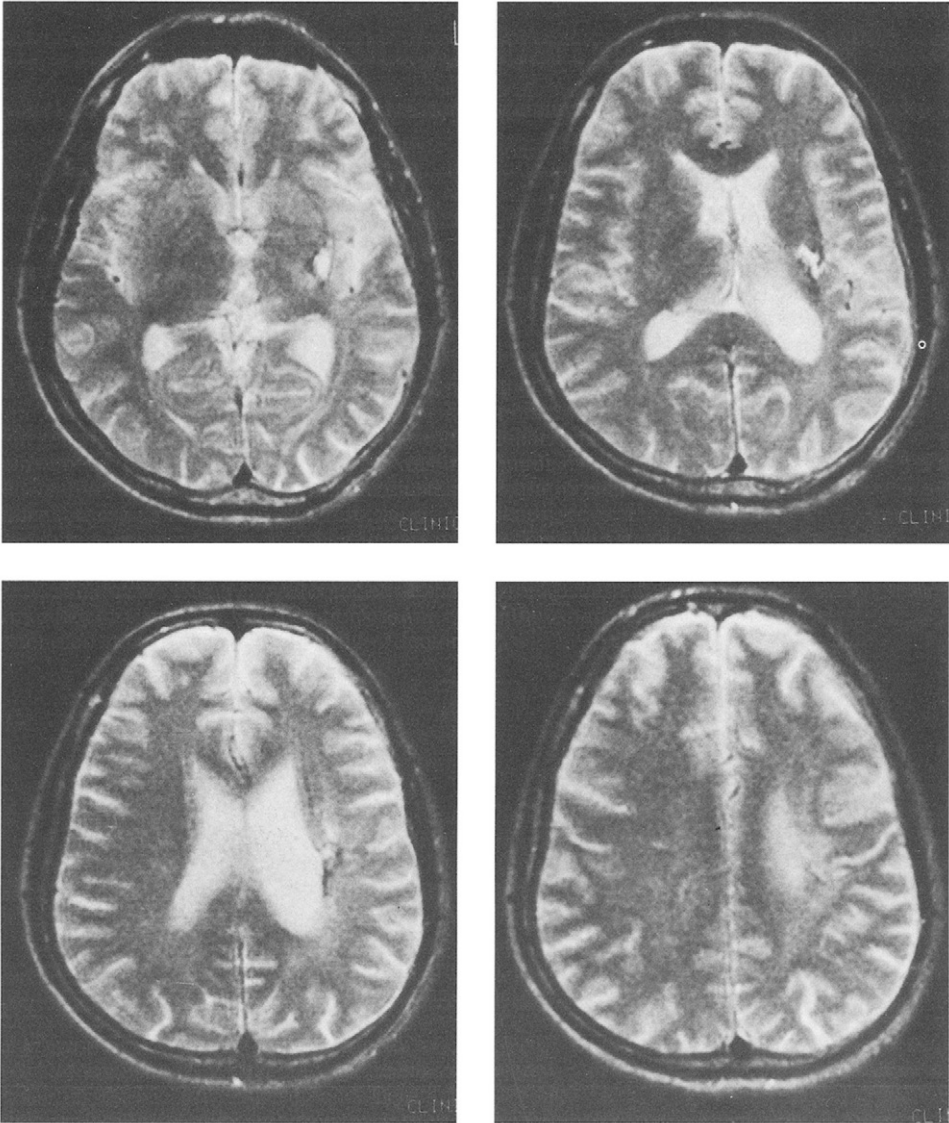


Fig. 2 – Representative cuts of the MRI scan performed 1 year post onset. The sections show the long-term effects of a large putaminal hemorrhage in the left hemisphere. Notice putaminal hemosiderosis. The lesion involves the putamen and extends to the frontal and parietal white matter above the putamen. There is consensual enlargement of the posterior frontal and of the parietal portions of the left lateral ventricle, and leucoencephalopathy of posterior frontal and parietal white matter.

naming ($\chi^2 = 6.388$; $p < .02$). He produced comparable numbers of incorrect lexical responses in oral (4, or 6.9% of total responses) and in written naming (3, or 6.8% of total responses). In writing, however, SFI also produced 9 errors (20.5% of total responses) that were orthographically related to the target. In other words, in writing he often retrieved the correct lexical entry, but made errors in spelling it (e.g., *pennello*, paintbrush → *pe_nello*; *quadro*, painting → *quatro*; *tingere*, to dye → *tincere*; *annaffiare*, to water → *anna_fiare*). Five of the errors (out of a total of 9) involved the deletion of a consonant in a geminate

cluster. Oral production tasks revealed that SFI's speech was mildly slowed by dysarthria and word-finding pauses. Furthermore, he occasionally omitted grammatical morphemes and the main verb, but produced a normal variety of grammatical structures, including passives.

Spontaneous writing was slow but accurate. SFI produced a normal variety of grammatical structures and wrote passive sentences proficiently, but made numerous spelling errors, similar to those observed in other writing tasks. For example, in a written account of his daily activities, "While I wait for my wife to visit me, I read a book", was written *Mentre aspeto* (for *aspetto*) *che giuga* (for *giunga*) *mia moglie mi lego* (for *leggo*) *un libro*.

To sum up, SFI showed a very mild aphasic deficit. Performance in auditory and visual input processing tasks (auditory and visual lexical decision, grammaticality judgement, word- and sentence-to-picture matching) was within normal limits. Oral production of pseudowords, words and sentences was very mildly impaired (the impairment was slightly more evident in reading than in other tasks). SFI's major deficit involved writing. He produced spelling errors in all tasks that required the production of a written response, independent of the modality in which input was presented (spontaneous writing, writing to dictation, written naming). An interesting feature of SFI's performance is that many spelling errors involved the production of geminate consonants. The latter difficulty also appears to result from an output deficit: SFI made errors with double letters in all writing tasks but his performance in auditory discrimination of geminate consonants was flawless. The following two sections

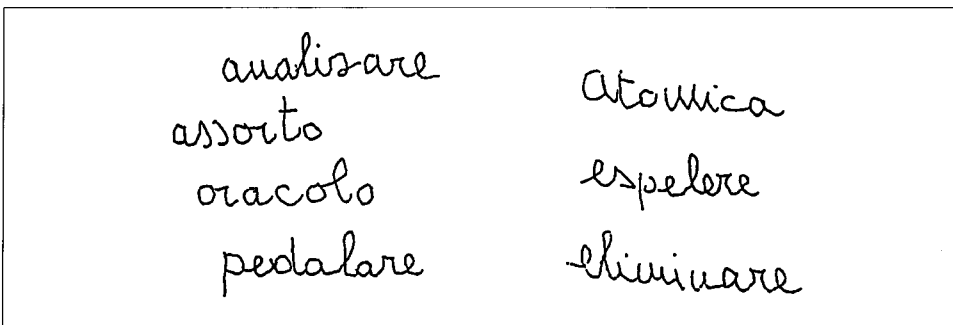


Fig. 3 – Samples of SFI's responses in writing to dictation. Some incorrect (*analizare* for *analizzare*, and *espeleze* for *espellere*) and some correct responses are shown.

of the paper are devoted to the identification of the locus of impairment responsible for SFI's spelling errors, and to a detailed analysis of his difficulty with geminate consonants.

Analysis of Performance in Experimental Tasks

SFI was presented with 356 words and 174 pseudowords, that he was asked to write to dictation. He never asked for repetition of the stimulus, and always wrote with his left hand, slowly but very legibly. A sample of his handwriting is presented in Figure 3. Whenever he felt that he had made an error, he was instructed to cross out his response, and to start again from the beginning.

SFI produced the correct response to 308/356 (86.5%) words and to 114/174 (65.5%) pseudowords. Overall performance was significantly more accurate with words than with pseudowords ($\chi^2 = 29.455$; $p < .001$). A mild length effect was observed in both word and pseudoword writing (Table I). In word writing, SFI produced the correct response to 63/67 (94%) stimuli of 4-5 letters and to 17/22 (77.3%) stimuli of 10 or more letters. In pseudoword writing, SFI correctly produced 14/16 (87.5%) stimuli of 4/5 letters, but only 39/69 (56.5%) stimuli of 8-9 letters. Accuracy of response to words was not affected by lexical factors (frequency, form class, morphological structure, abstractness); accuracy of response to pseudowords was not influenced by the presence of morphemic constituents in

TABLE I
 Correct Responses Produced by SFI in Writing to Dictation Words and Pseudowords of Various Lengths (percentages are in parentheses)

Length	Words	Pseudowords
4-5	63/67 (94.0)	14/16 (87.5)
6-7	101/114 (88.6)	54/80 (67.5)
8-9	127/153 (83.0)	39/39 (56.5)
10-12	17/22 (77.3)	7/9 (77.8)
Total	308/356 (86.5)	114/174 (65.5)

the to-be-produced string. Only 4/48 incorrect responses to words (8.3%) and 1/60 responses to pseudowords (1.7%) were words. Three out of four incorrect word responses in word writing were produced to 5-letter stimuli with 5 or more orthographic neighbors (by the N-count criterion (Coltheart, Davelaar, Jonasson et al., 1977) there were no such stimuli in the pseudoword corpus).

A qualitative error analysis was subsequently carried out. All the incorrect responses produced by SFI could be construed as letter substitutions (*editore*, editor → *edidore*), insertions (*brivido*, shiver → *ibrivido*), exchanges (*immorale*, immoral → *immolare*, to sacrifice), and deletions (*prossima*, next → *pro_sima*; *brutto*, ugly → *b_utto*, I throw away), or as combinations of two of these error types. Examples of the latter error types are *metronomo*, metronome → *metromeno*, where two letters were exchanged (m and n), and a third letter was substituted (e for o), and *pubblico*, public → *puplico*, which was scored as a letter substitution (p for b) and a geminate deletion. All (48/48) incorrect responses produced by SFI to words and 58/60 of his incorrect responses to pseudowords were retained for analysis since a reliable interpretation was possible for each response (two uninterpretable responses to pseudowords (*sagnodi* → *salosli*, and *nedasbori* → *metavoi* were excluded from this and the following analyses). Strings in which only one type of error occurred (even when it occurred more than once) accounted for comparable numbers of incorrect responses to words (43/48, or 89.6%) and pseudowords (51/60, or 85%).

The number of letters involved in errors of various types in both word and pseudoword writing is shown in Table II. Remarkably similar distributions of error types were obtained: substitutions (46.6% on words, 44.1% on pseudowords), insertions (3.4% on words, 3.9% on pseudowords), exchanges (6.9% on words, 5.2% on pseudowords) and deletions (43.1% on words, 46.8% on pseudowords) occur with the same frequency in incorrect responses to words and to pseudowords. Substitutions and deletions were the most frequent error types for both types of stimuli.

This pattern of performance — no effect of lexical variables in word writing, no effect of morphological structure in pseudoword writing, length effect, and similar distribution of errors types across words and pseudowords — suggests that SFI's writing disorder results from damage at the level of the graphemic buffer (Caramazza, Miceli, Villa et al., 1987).

TABLE II
 Distribution of Incorrectly Produced Letters across Various Error Types in Word and Pseudoword writing (percentages are in parentheses)

	No. of letters in errors		
	Words	Pseudowords	Total
Substitutions	27 (46.6)	34 (44.1)	61 (45.2)
Insertions	2 (3.4)	3 (3.9)	5 (3.7)
Exchanges	4 (6.9)	4 (5.2)	8 (5.9)
Deletions	25 (43.1)	36 (46.8)	61 (45.2)
Total	58 (100)	77 (100)	135 (100)

Analysis of Errors on Geminate Clusters

Analysis of Letter Deletions in Geminate vs. Non-geminate Consonant Clusters

The most intriguing feature of SFI's performance was the high rate of deletions of one letter of geminate clusters, as *bloccare* → *blo care*. Errors of this type occurred in all writing tasks. These errors offer the opportunity to evaluate the claim that information about the identity and number (one or two) of letters in a word are specified at separate levels of representation — the grapheme tier and the quantity tier in Figure 1, respectively. This hypothesis predicts that letter deletions in geminate clusters and in non-geminate clusters should result from damage to distinct types of information in graphemic representations. A geminate consonant deletion should result from damage to the quantity tier, whereas deletion of a consonant in a non-geminate cluster should result from damage to the grapheme tier. Thus, if information at the quantity level is "lost", for example as the consequence of brain damage, many deletion errors should occur in geminate clusters but not in non-geminate clusters. As an alternative hypothesis, it could be argued that information about quantity does not have any special status in graphemic representations. In this case, the two consonants in a geminate cluster would occupy two positions in the grapheme tier, just like the consonants in a non-geminate cluster (compare the words *matton*e and *carton*e in Figures 4a and 4b). This hypothesis makes a very different prediction, namely, that consonants in both geminate and non-geminate clusters should be equally exposed to deletion. To evaluate these competing hypotheses about the structure of graphemic representations, a detailed analysis of consonant deletions in two-consonant clusters was carried out for the corpus of words and pseudowords written by SFI.

Geminate clusters (*tetto*, *roof*) and non-geminate clusters of both the ambisyllabic type

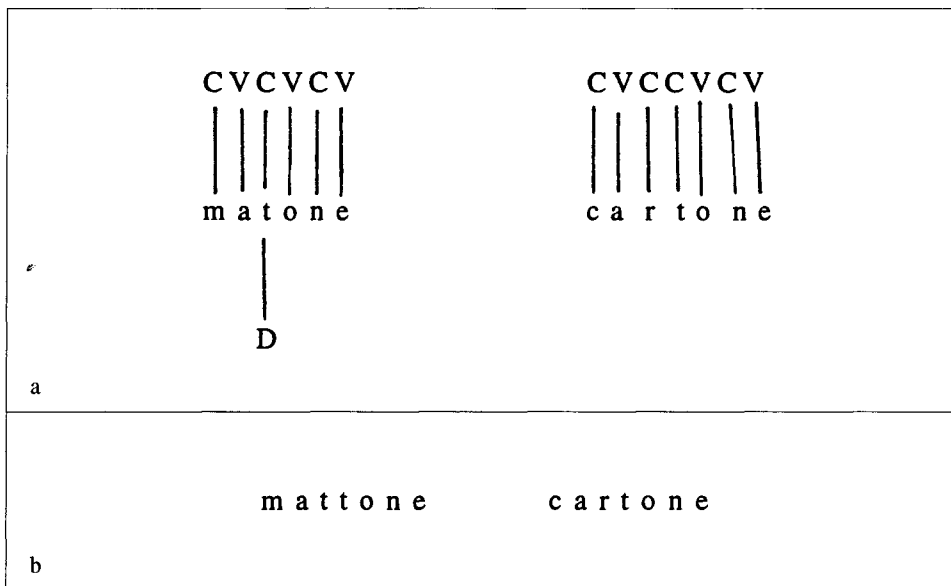


Fig. 4 - (a) Comparison of the graphemic representations for the words *matton*e and *carton*e according to Caramazza and Miceli (1990). Note that while the grapheme ⟨t⟩ in *matton*e is associated with a doubling marker resulting in the production of two Ts, the grapheme ⟨rt⟩ in *carton*e occupy two independent position. (b) The graphemic representations for the words *matton*e and *carton*e for the hypothesis which assumes no special status for geminate clusters. Note that there is no representational difference between the two Ts in *matton*e and the RT sequence in *carton*e.

TABLE III
Incidence of Consonant Deletions in Geminate and in Non-geminate Clusters across Tasks
(percentages are in parentheses)

	Geminate	Non-geminate
Dictation, pseudowords	19/41 (46.3)	7/121 (5.8)
Dictation, words	22/109 (20.2)	2/228 (1.8)
Written naming	5/16 (31.2)	0/21 (0.0)
Spontaneous writing	6/31 (19.4)	1/35 (2.9)
Total	52/197 (26.4)	12/405 (3.0)

(*ponte*, bridge) and the tautosyllabic type (*padre*, father) were considered¹. All geminate clusters and all ambisyllabic clusters were included, as well as tautosyllabic clusters in non-initial stimulus position. Tautosyllabic clusters in stimulus-initial position (*trama*, plot) were excluded, because neither geminate nor ambisyllabic clusters can occur in that position. This choice was made to insure that performance with geminate clusters could be compared with non-geminate clusters in comparable positions within the stimulus.

The incidence of consonant deletions in geminate and non-geminate clusters across tasks (writing to dictation, written naming, narrative writing) and stimulus types (words and pseudowords) is reported in Table III. Independent of cluster type, deletions always involved only one consonant. The analyses reported here collapsed across ambisyllabic and tautosyllabic clusters. However, all the comparisons between geminate and non-geminate clusters reported in this paper were also carried out separately (between geminate and ambisyllabic, geminate and tautosyllabic, ambisyllabic and tautosyllabic clusters). In all comparisons, performance on geminate clusters differed significantly from performance on other clusters, and performance on ambisyllabic and tautosyllabic clusters was indistinguishable.

Overall, deletions occurred significantly more frequently in geminate clusters (52/197 - 26.4%) than in non-geminate clusters (12/405 - 3.6%): chi-square = 74.150; $p < .001$. In word writing tasks, SFI deleted a consonant in 33/156 (21.2%) geminate clusters but in only 5/284 (1.8%) non-geminate clusters. This difference was highly significant (chi-square = 45.568; $p < .001$). Geminate deletions occurred with comparable frequency across tasks: 22/109 (20.2%) in writing to dictation, 5/16 (31.2%) in written naming, and 6/31 (19.4%) in spontaneous writing. In writing pseudowords to dictation, SFI also deleted a consonant more frequently in geminate clusters (19/41 - 46.3%) than in non-geminate clusters (7/121 - 5.8%). This difference was also highly significant (chi-square = 34.435; $p < .001$).

In short, the results of the analyses based on consonant deletions across cluster types clearly show that double letters are processed differently from other consonant clusters. These results are consistent with the hypothesis that grapheme identity and quantity are represented independently, and they are incompatible with the alternative hypothesis that geminates do not have a special status in the representation of graphemic information.

Analysis of Substitution Errors in Geminate vs. Non-geminate Consonant Clusters

The multidimensional graphemic representation hypothesis schematized in Figure 1 also has implications for the incidence and type of substitution errors that are likely to occur in geminate and non-geminate clusters. Under the account that identity and quantity are separately represented, geminate consonants occupy only one position in the grapheme identity tier. Thus, if this tier is damaged, consonant substitutions in geminate clusters should be of the all-or-none type — if grapheme identity is preserved, both geminate consonants should be produced correctly; if grapheme identity is lost, both geminate consonants should be substituted. As a consequence, in case of damage to the grapheme identity tier, (1) the

¹ By ambisyllabic geminate clusters we mean those clusters in which the first consonant is the coda of the preceding syllable. By tautosyllabic cluster we mean those clusters in which both consonants are part of the onset of the current syllable.

probability that both geminates are substituted should not differ from the probability that one consonant in non-geminate clusters is substituted (in these clusters, the two letters occupy two positions in the grapheme identity tier), and (2) the probability that only one of the geminate consonants is substituted should be lower than the probability that only one of the non-geminate consonants is substituted².

We have already documented that SFI suffers from mild damage to the grapheme identity tier — he substituted many letters, and inserted or exchanged a few (Table II). Thus, we can analyze the distribution of substitution errors produced by SFI in order to test the hypothesis of a special representational status for geminates. To evaluate the prediction that the probability of substituting both letters in a geminate cluster should be the same as the probability of substituting a single letter in a non-geminate cluster, the number of substitutions of a geminate cluster was compared to the number of substitutions of non-geminate consonants. Unfortunately, this prediction could not be evaluated directly, since SFI never produced incorrect responses resulting from 'pure' substitutions of geminate consonants (errors like *capello*, *hair* → *capecco* did not occur). However, he produced some multiple-type errors in which the geminate feature was deleted, and the correct grapheme was substituted by an incorrect letter (*pubblico* → *puplico*). Since the corpus collected from SFI contained 197 target geminate clusters and 405 non-geminate ambisyllabic clusters, the comparison was based on the substitutions produced on the 197 geminate clusters (or grapheme types) and on the 810 consonants in non-geminate clusters. SFI substituted a consonant in 4/197 (2%) grapheme types (or geminate clusters) and in 22/810 (2.7%) non-geminate clusters (chi-square = 0.086; *p* = n.s.). That is, double letters appear to behave as a single letter, as predicted by the hypothesis that geminates are represented by a single grapheme type with a doubling feature, and not two grapheme tokens.

In order to test the second prediction — that substitutions of a single letter in a geminate cluster should be much fewer than such substitutions in other consonant clusters — we compared the incidence of substitutions for the 394 consonants in the 197 geminate clusters with that for the 810 consonants in 405 non-geminate clusters. SFI substituted 2/394 (0.5%) consonants in geminate clusters (*fredda* → *frenda*; *processo* → *procesco*) and 22/810 (2.7%) consonants in non-geminate clusters. This difference is highly significant (chi-square = 30.609; *p* < .001). As predicted, single consonants in geminate clusters are virtually immune from being substituted, whereas substitutions of just one consonant in a non-geminate cluster are not nearly as uncommon.

In short, the distribution of substitution errors, just like the distribution of deletion errors, is consistent with the hypothesis that geminate clusters have a special representational status in graphemic representation.

DISCUSSION

There are several features to SFI's performance that are relevant in the present context. First, there is the observation that he deleted one of the two consonants in geminate clusters nearly 10 times as often as he deleted one of the two consonants in position-matched non-geminate clusters. Second, there is the fact that SFI virtually never substituted only one of the consonants in a geminate cluster (the only exceptions occurred on the first day of testing and never again) but he (relatively) frequently substituted one of the two consonants in non-geminate clusters. Third, there is the observation that the frequency of occurrence of substitution errors for a given grapheme is independent of the number of consecutive tokens (one or two) of the grapheme in a word. These facts are inconsistent with the hypothesis that geminate consonants are represented as two independent tokens. Instead, they forcefully argue for the hypothesis that information about grapheme identity is represented independently of information about their number.

Equally important in the present context is the observation that SFI did not have particular

² Actually, if all other processing components were to function normally, then, the probability of substituting only one consonant of a geminate cluster should be zero.

difficulties processing geminates in the auditory/oral modality. That is, SFI had no difficulties in auditorially discriminating geminate from non-geminate consonants (*lego-leggo*), nor did he have difficulties in orally producing geminate consonants (which are phonemically distinctive in Italian). The implication of these facts is that SFI's deficit specifically concerned the processing of orthographic information and that the selective difficulty with geminates in this modality cannot be attributed to a more general problem in phonological processing.

The pattern of results reported for SFI together with previously reported results (Caramazza and Miceli, 1990; McCloskey et al., 1994; Tainturier and Caramazza, 1995) allow us to adjudicate between two variants of how double letters are represented in a multidimensional graphemic structure. One hypothesis, the one entertained in this report, assumes that letter doubling information is independently specified by a doubling marker or feature (Caramazza and Miceli, 1990; see also Houghton, Glasspool and Shallice, 1995; Rumelhart and Norman, 1982; Shaffer, 1975, 1976; Sternberg, Knoll and Turock, 1990). An alternative hypothesis assumes that quantity information is specified by associating each grapheme in a word with a position-marking element (Caramazza and Miceli, 1989) or slot (McCloskey et al., 1994) in the position tier. On this hypothesis, doubling information is specified by associating one grapheme identity with two positions in the position tier. Thus, both hypotheses draw a distinction between the representation of graphemic identity and quantity. However, they differ in the formalism for representing the hypothesized quality/quantity distinction.

The two hypotheses can account for a wide range of observations regarding performance with double letters. Thus, for example, both hypotheses can account for the fact that substitutions follow the all-or-none pattern, and both can account for the pattern of geminate transposition errors. However, it would seem that only one of the two hypotheses — the doubling feature hypothesis — naturally accounts for the selective deletion performance reported for SFI. On this hypothesis, letter doubling is specified by an independent feature which we can imagine being selectively affected by brain damage, leading to the selective loss of doubling information and the deletion of one of the two consonants in a geminate cluster. By contrast, it is not obvious how the alternative hypothesis — the double position association hypothesis — can naturally account for the selective deletion errors with geminates. If one were to argue that the reported deletion errors result from a deficit in the grapheme-to-position associating mechanism, then, we would also expect many errors of transposition since on this hypothesis order of graphemes is specified through the association of grapheme identities with the position tier. However, there were very few such errors, as may be seen in Table II. Thus, although the evidence is not very strong, it would seem that the doubling feature hypothesis is to be preferred to the double position association hypothesis.

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